What's New in MRI of Peripheral Nerve Entrapment?

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• Ulnar nerve • Piriformis syndrome • Peroneal nerve

MRI of the peripheral nervous system has been performed since the 1980s. As equipment has improved and experience with common entrapment syndromes and neuropathies has accumulated, general principles have emerged that have subsequently been applied to less common entrapment and injury syndromes. This review focuses primarily on new developments in the imaging of entrapment syndromes, covering the imaging literature in the period from 2003 to early 2008. Recent reviews have appeared on related topics, including the imaging of peripheral nerve tumors[1–3] and the use of MRI in the surgical management of a variety of peripheral nerve disorders,[4] and the reader is referred to these articles for additional information. Although ultrasound has also been used in the evaluation of superficial entrapment neuropathies, particularly in the upper extremity,[5,6] it is operator-dependent, unable to penetrate bone or gas, and gives information primarily on nerve size. Its clinical use to date has been limited, and it is not discussed further here.

We begin with a brief review of the principles of peripheral nerve imaging with MRI, particularly as applied to entrapment syndromes and their clinical mimics. Although MRI has reached a state of relative technologic maturity in 2008, novel techniques for imaging peripheral nerve pathologic findings are likely to become important. We discuss three promising methods: diffusion imaging, three-dimensional (3D) imaging, and the use of new contrast agents and their possible clinical applications. We then describe new developments in the imaging of entrapment neuropathies of the upper and lower extremities. We conclude with a discussion of future directions for research that are open and are likely to prove clinically useful.

BASICS OF PERIPHERAL NERVE IMAGING

The basic principles of peripheral nerve imaging have been well summarized in recent reviews [4,7,8] and are straightforward. A peripheral nerve is best imaged in two planes (one perpendicular to the nerve and the other parallel to the nerve), with T1 and STIR (short tau inversion recovery) images acquired in one or both planes. T2 images have exquisite resolution, although pathologic findings are generally not as conspicuous as on STIR imaging. A normal nerve appears similar to muscle on all images. An entrapped nerve generally has an edematous appearance, with an increase in T2 and STIR signal over the abnormal segment; the nerve may also be enlarged proximally to a point of constriction. It is often useful to acquire both STIR and T2 images in at least one plane. In the

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case of focal entrapments (eg, see the discussion of the ulnar nerve at the elbow in what follows), the most abnormally appearing segment is generally proximal to the point of entrapment, although STIR or T2 signal abnormality can persist distal to the point of entrapment. The fascicular structure of the larger nerves is often visible, and in the case of entrapment, only a portion of the fascicles may be bright, giving the nerve a speckled appearance. The location of the abnormally appearing nerve segment provides a useful clue to the location and, frequently, the cause of the entrapment. When imaged, muscles that are innervated by branches arising distal to the point of entrapment may be bright on STIR and T2 images; in the case of small branches, such as the anterior and posterior interosseous nerves (PINs) of the upper extremity, this can confirm the identity of the entrapped nerve.[9] An early study at lower field (1.0 T) showed that abnormally T2-bright muscles were generally nearly the same as those showing abnormality on electromyography (EMG) in the form of positive sharp waves or fibrillation potentials.[10] It is also known that after nerve injury, MRI changes in denervated muscle preceded EMG changes. It is possible, therefore, that muscle imaging with MRI may actually be more sensitive to denervation than EMG. Inflammatory conditions of the peripheral nervous system may have a similar appearance to entrapment, but the area of involvement is frequently more diffuse. Peripheral nerve tumors (most commonly, neurofibromas, followed by schwannomas and, rarely, solitary circumscribed neuromas, which are benign tumors of the head and neck) present as discrete contrast-enhancing masses related to nerves. Although inflammatory conditions of the nerves, tumors, and traumatic neuromas enhance with current MRI contrast agents, entrapped nerves do not enhance.

NEWER MRI TECHNOLOGIES IN PERIPHERAL NERVE IMAGING

Perceived MRI ''quality'' depends on spatial resolution (voxel size) and signal-to-noise ratio; for a given pulse sequence and receiver coil design, the signal-to-noise ratio is roughly proportional to the product of field strength, the square root of voxel volume, and the square root of imaging time. For example, by going from a field strength of 1.5 T to 3 T, the twofold gain in signal to noise can be ''spent'' either by decreasing acquisition time by a factor of 4 or, if acquisition time is kept constant, by decreasing the pixel size and the field of view by approximately 30%. Although these figures are only approximate, the point is that there are practical limits to the improved spatial resolution that is possible by going to higher fields. Modern MRI systems have optimized signal to noise by (1) improvements in receiver electronics, which means that the dominant source of image noise arises from the patient; (2) the widespread use of multielement (''phased array'') coils, which achieve near-optimal signal-to-noise ratios for externally applied coils; and (3) increases in field strength from 1.5 T to 3 T. Further significant increases in signal to noise, and therefore in spatial resolution, seem relatively unlikely, because the signal-to-noise improvement possible with array coils is limited by the ratio of the size of the anatomy of interest (a nerve) to its distance from the surface of the body. Marked improvement in resolution can still be obtained by going to ex vivo imaging of excised nerves (**Fig. 1**),[11,12] which permits the use of high fields, long imaging times, and coils that surround and are only slightly larger than the nerve itself. Although such images are not, and probably never will be, obtainable in vivo, they are potentially useful for better understanding the impact of particular pathologic findings on the appearance of the nerve in clinical images.

The diagnostic value of a particular type of clinical image often depends more on the contrast between normal and pathologic tissues, which determines the conspicuity of pathologic findings, than on signal-to-noise ratio per se. Diagnostic value can be enhanced by devising new pulse sequences or contrast agents that increase the conspicuity of subtle nerve abnormalities. Some recent developments along these lines with potential applications in peripheral nerve imaging have been described. The first is the use of diffusion imaging, which has been widely used in the imaging of stroke and, more recently, in the imaging of white matter tracts in the brain and spinal cord. Diffusion imaging is exquisitely sensitive to the presence of tissue anisotropy, and should thus be ideal for the study of peripheral nerves, which are highly longitudinally organized at the microscopic level. To date, the practicality of diffusion imaging in the larger nerves (eg, median, ulnar, sciatic) has been demonstrated (**Fig. 2**).[13–15] Diffusion tensor imaging measures the rate of microscopic water diffusion in all spatial directions at every voxel. After eliminating the ''isotropic'' voxels in which no single dominant direction of fastest diffusion exists, continuous streamlines are traced from a set of seed voxels, always following the dominant direction in successive voxels, until an isotropic voxel is encountered. When this is done, the streamlines starting from seed points within a proximal portion of the nerve tend to follow the course of the normal nerve fibers distally (see **Fig. 2**). The bottom row of **Fig. 2**,